Multifocal intraocular lenses in cataract surgery: Literature review of benefits and side effects

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This literature review looks at the current status of multifocal intraocular lenses (IOLs) in cataract surgery. The results of implantation of multifocal IOLs of diffractive, refractive, and hybrid diffractive–refractive design are described with regard to uncorrected near and distance visual acuity and spectacle independence. The occurrence of photic phenomena and contrast sensitivity loss with multifocal IOLs are also addressed.

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Accommodation is the ability of the eye to dynamically change its optical power to create a sharp image of distant, intermediate, and near objects on the retina.[1] Helmholtz[2] pioneered the theory that accommodation is the result of changes in the optical power of the crystalline lens as a result of changes in the lens shape and position due to changes in tension exerted on the zonular fibers after relaxation or contraction of the ciliary muscle. As people age, the ability to accommodate decreases, resulting in presbyopia.[3] This is thought to be the result of changes in the elasticity of the crystalline lens[4,5] and in the contractility of the ciliary muscle.[6,7] Thus, even emmetropic subjects who were spectacle independent when they were younger will become dependent on spectacles for near vision once they become presbyopic.

Apart from the age-related changes in the crystalline lens that lead to presbyopia, age-related changes in the proteins in the crystalline lens lead to cataract formation.[8] Cataract surgery with implantation of an intraocular lens (IOL) has the potential not only to increase visual acuity, but also to change the patient's refractive state. Ideally, an IOL would allow the presbyopic patient to regain his or her ability to accommodate. Although refilling the capsular bag with a clear but elastic substance would theoretically lead to the desirable result, experiments in this area have been unsuccessful.[9] Similarly, a change in position of the IOL or parts of it within the optical system would change the optical power of the optical system as a whole, thus providing the patient with the ability to accommodate.[10] Ultrasound studies have shown changes in the position of accommodating IOLs within the optical system in response to physiological or pharmaceutical stimuli,[11] although other studies have not found significant movement of these IOLs.[12,13] In clinical practice, movement of accommodating IOLs has been shown to be insufficient to result in large changes in the power of the optical system.[10,14]

Apart from strategies to provide IOLs with a dynamic optical power or position within the optical system, IOLs can be designed to provide 2 or more fixed optical powers. So-called multifocal IOLs have been designed to result in 2 or more coexisting retinal images in which only the image corresponding to the distance or near focal point is sharp. This concept is known as *simultaneous vision*,[15] although *simultaneous imaging* would be a more appropriate term. Multifocal IOLs have 2 or more fixed adapting focal points rather than 1 and are therefore pseudoaccommodative rather than truly accommodative.

The earliest multifocal IOLs were introduced in the late 1980s.[16,17] As presented in Table 1, multifocal IOLs using refractive, diffractive, and combinations of both optical principles have been developed. Refraction is based on a change in direction of the light ray due to a change in the optical density of the material transmitting the light ray. Diffraction is based on the observation that light that encounters a discontinuity

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Table 1. Characteristics of multifocal IOLs.

IOL	Company	Design	Pupil	Near Add (D)	Toric	Aspheric
AcriLISA (366D, 376D, 536 D) AT LISA (801, 802, 809M)	Carl Zeiss Meditec	Diff + Ref	Independent	+3.75	No	Yes
Acri.LISA toric (466TD) AT LISA toric (909M)	Carl Zeiss Meditec	Diff + Ref	Independent	+3.75	Yes	Yes
Acri.Twin (733 + 737)	Acri.Tech/Carl Zeiss Meditec	Diff	Independent	+4.0	No	Yes
AcriviaReviol (BB MF 613, BB MFM 611)	VSY Biotechnology	Diff	Independent	+3.75	No	Yes
Array (SA40N, SA40NB)	Abbott Medical Optics	Ref	Dependent	+3.50	No	No
CeeOn 811E*	Pharmacia	Diff	Independent	+4.0	No	No
FineVision	Physiol	Diff, trifocal	Dependent	+1.75, +3.50	No	Yes
LentisMplus (LS-312MF 15)	Oculentis GmbH	Ref, sector-shaped near zone	Independent	+1.50	No	Yes
LentisMplus (LS-312MF 30, LS-313MF 30)	Oculentis GmbH	Ref, sector-shaped near zone	Independent	+3.00	No	Yes
LentisMplus toric (LS-312T1-T6, LS-313T1-T6)	Oculentis GmbH	Ref, sector-shaped near zone	Independent	+3.00	Yes	Yes
M-flex (580F, 630F)	Rayner Ltd.	Ref	Dependent	+3.00, +4.00	No	Yes
M-flex T (588F, 638F)	Rayner Ltd.	Ref	Dependent	+3.00, +4.00	Yes	Yes
MS 6125 Diff	Dr. Schmidt Intraocular Linsen	Diff	Dependent	+3.50	No	Yes
MS 614 Diff	Dr. Schmidt Intraocular Linsen	Diff, sulcus	Dependent	+3.50	No	Yes
MS 714 PB Diff	Dr. Schmidt Intraocular Linsen	Diff, sulcus, add-on	Dependent	+3.50	No	Yes
MS 714 TPB Diff	Dr. Schmidt Intraocular Linsen	Diff, sulcus, add-on	Dependent	+3.50	Yes	Yes
OptiVis	Aaren Scientific	Diff	Dependent	+2.80	No	Yes
PA 154N*	Allergan	Ref	Dependent	+3.50	No	No
PY-60MV*	Hoya	Ref	Dependent	+3.00	No	No
ReStor (SA60D3, SN60D3, MN60D3)	Alcon Laboratories	Diff + ref	Dependent	+4.00	No	No
ReStor (SN6AD1, SN6AD3)	Alcon Laboratories	Diff + ref	Dependent	+3.00, +4.00	No	Yes
ReStor (SND1-T2/3/4/5)	Alcon Laboratories	Diff + Ref	Dependent	+3.00	Yes	Yes
ReZoom (NXG1)	Abbott Medical Optics	Diff + ref	Dependent	+3.50	No	No
SFX MV1*	Hoya	Ref	Dependent	+2.25	No	No
Sulcoflex multifocal (653F)	Rayner Ltd.	Ref, sulcus, add-on	Dependent	+3.50	No	No
Sulcoflex multifocal toric (653Z)	Rayner Ltd.	Ref, sulcus, add-on	Dependent	+3.50	Yes	No
Tecnis (ZM900, ZMB00)	Abbott Medical Optics	Diff	Independent	+4.00	No	Yes
TrueVista 68STUV*	Storz	Ref	Dependent	+4.00	No	No

Diff = diffractive; IOL = intraocular lens; Ref = refractive
*No longer available

or edge in the material in which it travels scatters in numerous directions. Light energy arriving at an edge or discontinuity can thus be divided over 2 or more focal points, similar to refractive IOLs. Both effects were described by Fresnel in 1822[18] when working on lenses for lighthouses and can be used to design IOLs with multiple focal points. The type of optics used influences the clinical results of the IOL, as will be described later.

More recently, so-called aspheric multifocal IOLs have been introduced. In these IOLs, optical properties of the IOL have been altered to decrease higher-order aberrations (HOAs) of the total optical system, primarily by compensating for the increased spherical aberration of the cornea in older subjects.[19,20] Studies comparing aspheric and spherical monofocal IOLs have reported superior visual performance of aspheric IOLs compared with their spherical counterparts, especially with respect to mesopic visual acuity and contrast sensitivity.[21,22] In the case of multifocal IOLs, implantation of aspheric IOLs has been found to result in superior[23] or equal[24] visual performance compared with their spherical counterparts.

Apart from refractive versus diffractive designs and spherical versus aspheric designs, multifocal IOL designs can be described as pupil dependent or pupil independent. In zonal refractive designs and designs with a central diffractive structure, the division of the light energy is dependent on pupil size. Intraocular lens designs with a similar peripheral and central optical zone are pupil independent. The differences between multifocal IOL designs are best illustrated in ray-tracing studies[25] and optomechanical eye-model studies.[26] This article describes the available designs as well as the results and side-effects of implanting multifocal IOLs following cataract surgery as reported in the English and German peer-reviewed literature.

MATERIALS AND METHODS

Bibliographic research was performed in Pubmed/Medline and most recently updated May 1, 2012. Keywords used were "multifocal intraocular lens," "multifocal intraocular lenses," "multifocal IOL," and the respective brand names shown in Table 1. Articles were included when they reported on clinical trials, adult patients with cataract, bilateral surgery with a single type of multifocal IOL, absence of coexisting ocular pathology such as amblyopia, and absence of previous or subsequent corneal refractive procedures such as limbal relaxing incisions or laser refractive surgery. Papers were classified as randomized controlled trials (RCTs) or nonrandomized case series, with or without a control group. The RCTs were included regardless of the date of publication; case series were included if published after January 1, 2009. Data analysis focused on uncorrected distance visual acuity (defined as visual acuity measured at 4 to 6 meters) and uncorrected near visual acuity (defined as 30 to 50 centimeters, standardized for all subjects in the study or at the working distance preferred by the individual patient). The mean visual acuities are reported as logMAR units $\pm$ standard deviation, if necessary after conversion of reported alternative visual acuity units. A secondary outcome parameter noted was spectacle independence, defined as not using spectacles for distance, intermediate, and near vision tasks. Photic phenomena, such as glare, flare, and halos, intermediate visual acuity, and contrast sensitivity were not used as outcome parameters given the lack of uniformity in reporting these findings in the available papers, as described later.

Bibliographic Research and Data Analysis

The search for RCTs reporting the results of multifocal IOL implantation after phacoemulsification of the crystalline lens identified 18 papers. One paper was excluded from the current review because it reported the results of multifocal IOL implantation in refractive lens exchange rather than in cataract surgery.[27] A second paper was excluded because it reported the results of unilateral multifocal. IOL implantation.[28]

The search for nonrandomized case series, with or without control groups, published after January 1, 2009, reporting the results of multifocal IOLs identified 128 papers. Eighty-seven were excluded for reasons presented in Table 2. The 41 remaining studies were included in the current literature review.

Visual Acuity and Spectacle Independence

The results of the papers reporting on RCTs are presented in Table 3.[29–44] The results of the papers reporting on case series either comparing the results of different types of multifocal IOLs or reporting the results of a single type of multifocal IOL are presented in Table 4.[23,45–85]

DISCUSSION

Multifocal IOL implantation is aimed at providing patients with good uncorrected visual acuity for both

Table 2. Reasons for exclusion of 87 studies from the literature review.

Reason for Exclusion	Number of Studies
Outcome parameters other than visual acuity and spectacle independence used (stereopsis, perimetry, electroretinopgraphy, effects of simulated astigmatism, pupillometry, contrast sensitivity, intraocular straylight, wavefrontaberrometry)	16
In vitro study	13
Descriptions of postoperative complications (posterior capsule opacification, endophthalmitis, interference with intraoperative view during vitrectomy, autorefraction and optical coherence tomography, occurrence of dysphotopsia and other reasons for patient dissatisfaction)	11
Multifocal IOL combined with laser refractive surgery	8
Refractive lens exchange study population	5
Previously published results, comment on published paper, review	7
Unilateral and/or pediatric study population	6
Alternative techniques (scleral fixation of multifocal IOL, cyclosporine as adjuvant therapy)	4
Description of national practice patterns	2
Description of questionnaire for spectacle dependence	2
Monovision strategies	2
IOL of non-multifocal design	2
Different types of multifocal IOLs implanted in contralateral eyes	2
Cases of dissatisfied patients	2
Reporting visual acuities as median value only	1
Reporting visual acuities as percentages of patients only	1
Amblyopic cases	1
Age-related macular degeneration cases	1
Cost-benefit analysis	1

Table 3. Randomized controlled trials comparing results of implanting different types of multifocal IOLs.

Study*	Year	IOL Type (Number of Eyes)	UNVA (LogMar)	UDVA (LogMar)	Complete SI (% of Patients)
Santhiago[28]	2012	ReStor SN6AD1 (40)	0.022 ± 0.08	0.032 ± 0.07	90%
		ReStor SN6AD3 (40)	0.027 ± 0.02	0.023 ± 0.12	90%
Alio[29]	2011	ReStor SN6AD3 (38)	0.28 ± 0.04 logRAD	0.13 ± 0.13	-
		Acri.LISA 366D (42)	0.19 ± 0.08 logRAD	0.10 ± 0.11	
Santhiago[30]	2011	ReStor SN6AD1 (20)	0.022 ± 0.08	0.032 ± 0.07	90%
		ReStor SN6AD3 (20)	0.027 ± 0.02	0.023 ± 0.12	90%
Alio[31]	2011	ReStor SN6AD3 (78)	112 ± 22 wpm	0.15 ± 0.12	-
		Acri.LISA 366D (84)	115 ± 42 wpm	0.12 ± 0.11	
		ReZoom NXG1 (70)	101 ± 16 wpm	0.12 ± 0.13	
Alfonso[32]	2010	ReStor SN60D3 (20)	0.03 ± 0.05†	−0.04 ± 0.10†	-
		ReStor SN6AD3 (20)	−0.05 ± 0.06†	0.08 ± 0.10†	
		ReStor SN6AD1 (20)	−0.08 ± 0.04†	−0.06 ± 0.05†	
		Acri.LISA 366D (20)	−0.02 ± 0.08†	−0.08 ± 0.08†	
Santhiago[33]	2010	ReStor SN6AD3 (32)	0.03 ± 0.08†	0.02 ± 0.07†	-
		ReStor SN6AD1 (32)	0.02 ± 0.08†	0.03 ± 0.07†	
Maxwell[34]	2009	ReStor SN6AD3 (228)	0.12†	0.02†	81.2%
		ReStor SN6AD1 (232)	0.10†	0.02†	78.3%
Martínez-Palmer[35]	2008	Tecnis ZM900 (52)	0.06 ± 0.09‡	0.18 ± 0.10	77.0%
		ReZoomNXG1 (64)	0.22 ± 0.14‡	0.14 ± 0.12	44%
		Acri.Twin (64)	0.11 ± 0.12‡	0.16 ± 0.12	87.5%
Cillino[36]	2008	Array SA40N (32)	0.20 ± 0.06	0.06 ± 0.10	43.7%
		ReZoomNXG1 (30)	0.21 ± 0.10	0.07 ± 0.14	53.3%
		Tecnis ZM900 (32)	0.14 ± 0.11	0.16 ± 0.10	87.5%
Hütz[37]	2008	Array SA40N (20)	0.43 ± 0.14	-	-
		ReStor SA60D3 (20)	0.28 ± 0.15		
		Tecnis ZM001 (20)	0.16 ± 0.11		
Gunenc[38]	2008	Array SA40N (20)	20% ≥ J1† 40% ≥ J2†	90 % ≥ 20/25	60%
		CeeOn 811E (20)	90% ≥ J1† 100% ≥ J2†	80% ≥ 20/25	60%
Chiam[39]	2007	ReStor SA60D3 (100)	0.11	0.06	86%
		ReZoom NXG1 (100)	0.23	0.02	70%
Mester[40]	2007	Array SA40 (50)	0.40§	0.08†,§	33.3%
		Tecnis ZM900 (50)	0.22§	0.08†,§	82.6%
Hütz[41]	2006	Array SA40N (20)	69 wpm†	—	—
		Tecnis ZM001 (20)	166 wpm†		
		ReStor SA60D3 (20)	138 wpm†		
Leyland[42]	2002	Array SA40NB (58)	0.43 ± 0.16	0.06 ± 0.10	28%
		TrueVista (30)	0.46 ± 0.21	0.10 ± 0.15	33%
Liekfeld[43]	1998	CeeOn 811E (26)	0.04 ± 00.5	0.09 ± 0.12	—
		PA 154N (24)	0.32 ± 0.24	0.12 ± 0.10	

IOL = intraocular lens; J = Jaeger optotype; SI = spectacle independence; UDVA = uncorrected distance visual acuity; UNVA = uncorrected near visual acuity; wpm = words per minute
*First author
†Binocular
‡Binocular with distance correction
§Derived from figure

distance and near visual tasks. However, patients with a monofocal IOL can also have both good uncorrected distance and near visual acuity resulting from favorable corneal astigmatism[86,87]; favorable corneal wavefront aberrations[88,89]; or myopic undercorrection in 1 eye, resulting in pseudophakic monovision.[50,90] The RCTs[37,60,91–95] and metaanalyses of RCTs[96,97] comparing the results of multifocal IOL implantation with the results of monofocal IOL implantation conclude that uncorrected near vision is improved by implantation of a multifocal IOL, resulting in lower levels of spectacle dependence for near tasks without compromising distance visual acuity. The results of the current bibliographic search for papers in the peer-

Table 4. Nonrandomized studies reporting results of implanting different types of multifocal IOLs.

	Study*	Eyes	UNVA (LogMAR)	UDVA (LogMAR)	SI
Acri.LISA 366D	Alfonso[22]	40	−0.05 ± 0.07†	0.01 ± 0.18†	-
	Alió[44]	40	0.12 ± 0.12	0.10 ± 0.12	-
	Can[45]	30	0.08 ± 0.20	0.10 ± 0.07	100% (n) 96.6% (i) 100% (d)
	Castillo-Gómez[46]	20	0.06	0.15	-
	Fernández-Vega[47]	170	0.00 ± 0.02	0.07 ± 0.02	-
			0.00 ± 0.03	0.10 ± 0.16	
AcrivaReviol MFM 611	Can[45]	30	0.02 ± 0.05	0.07 ± 0.08	100% (n) 100% (i) 100% (d)
Array	Fujimoto[48]	72	0.24	0.06	34.7%
	Ito[49]	44	0.19 ± 0.12†	−0.10 ± 0.00†	-
AT LISA 909M	Mojzis[50]	23	0.24 ± 0.15	0.17 ± 0.13	-
		41	0.10 ± 0.09	0.12 ± 0.10	-
	Visser[51]	45	0.20 ± 0.16	0.04 ± 0.15	53%
LentisMplus LS-312 MF15	Alió[52]	22	0.45 ± 0.19	0.20 ± 0.14	-
LentisMplus LS-312 MF30	Alió[53]	43	0.21 ± 0.17	0.15 ± 0.21	-
	Alió[52]	21	0.21 ± 0.10	0.14 ± 0.11	-
	Alió[54]	24	0.30 ± 0.21	0.25 ± 0.33	-
	van der Linden[55]	90	0.16 ± 0.21	0.04 ± 0.15	-
	McAlinden[56]	44	162 wpm	0.04 ± 0.25	-
M-flex 630F	Aslam[57]	20	65% ≥ J6	0.18 ± 0.20	-
	Cezón-Prieto[58]	32	0.28 ± 0.11	0.09 ± 0.09	70% (n) 80% (i) 90% (d)
MS 714 PB	Gerten[59]	56	0.16 ± 0.13	0.10 ± 0.11	93.3%
	Wolter-Roessler[60]	50	0.20	0.05	-
Optivis	Piovella[61]	121	88.6% ≥ 0.10	84.1% ≥ 0.10	-
ReStor SA60D3, SN60D3, SN6AD3	Alfonso[22]	36	−0.04 ± 0.18†	0.02 ± 0.13†	-
	Alió[44]	40	0.19 ± 0.12	0.19 ± 0.18	-
	Blaylock[62]	74	0.06†	0.00†	-
	Chang[63]	30	0.07†	0.08†	72.7%
	Cionni[64]	190	0.11	0.05	80.6%
	Gierek-Ciacura[65]	20	0.11 ± 0.01	0.17 ± 0.02	80.0%
	Hayashi[66]	63	0.1§	0.1§	-
	Hida[67]	40	85% > J2	0.03 ± 0.05	-
	Mester[68]	40	0.24 ± 0.18‡	0.17 ± 0.22	-
	Petermeier[69]	30	0.0 ± 0.07†	0.0 ± 0.07†	100% (n) 80% (i) 93% (d)
	de Vries[70]	46	0.01 ± 0.05†	0.05 ± 0.12†	-
	Zelichowska[71]	46	-	0.03 ± 0.05	-

(*continued on next page*)

Table 4. (Cont.)

	Study*	Eyes	UNVA (LogMAR)	UDVA (LogMAR)	SI
ReStor SN6AD1	Alfonso[72]	40	$-0.04 \pm 0.06^{\dagger}$	$0.00 \pm 0.10^{\dagger}$	-
	Hayashi[73]	64	0.21	0.08	-
	Kohnen[74]	186	$-0.01 \pm 0.11^{\dagger}$	$-0.03 \pm 0.13^{\dagger}$	88%
	van der Linden[55]	143	0.05 ± 0.14	0.06 ± 0.25	-
	Mester[68]	40	$0.17 \pm 0.14^{\ddagger}$	$0.14 \pm 0.14^{\ddagger}$	-
	Petermeier[69]	24	$0.1 \pm 0.10^{\dagger}$	$0.0 \pm 0.05^{\dagger}$	92% (n) 83% (i) 92% (d)
	de Vries[70]	68	0.04 ± 0.12	0.04 ± 0.14	-
	Zhang[75]	42	$100\% \geq 0.10$	$90\% \geq 0.10$	81% (d)
ReZoom NXG1	Chang[63]	30	$0.17^{\dagger}$	$-0.01^{\dagger}$	50%
	Forte[76]	55	J2.3 $\pm$ 0.7	0.05 ± 0.09	-
	Gierek-Ciaciura[65]	20	0.20 ± 0.04	0.11 ± 0.01	70%
	Lin[77]	28	153 ± 44 wpm	$0.01^{\S}$	-
	Zelichowska[71]	46	-	0.03 ± 0.06	-
SFX MV1	Hayashi[78]	44	0.38	0.08	-
Sulcoflex multifocal	Khan[79]	4	$100\% \geq$ J4	$100\% \geq 0.10$	-
Tecnis ZM900, ZMB00	Akaishi[80]	2500	0.00 ± 0.00	0.06 ± 0.09	97.9 %
	Bautista[81]	70	78.6% J1	0.076 ± 0.014	-
	Castillo-Gómez[46]	20	0.11	0.08	-
	Gierek-Ciaciura[65]	20	0.12 ± 0.03	0.14 ± 0.02	80 %
	Packer[82]	244	0.16	0.04	84.8%
	Palomina-Bautista[83]	250	0.22 ± 0.08	0.14 ± 0.10	88.4%
	Yoshino[84]	30	0.19 ± 0.10	0.01 ± 0.10	86.7%

d = distance; i = intermediate; IOL = intraocular lens; J = Jaeger optotype; n = near; RLE = refractive lens exchange; SI = spectacle independence; UDVA = uncorrected distance visual acuity; UNVA = uncorrected near visual acuity
*First author
†Binocular
‡Binocular with distance correction
§Derived from figure

reviewed literature reporting on the results of bilateral implantation of multifocal IOLs in cataract surgery demonstrate that implantation of both refractive[37,64] and diffractive[33,37,64,71,75,98] multifocal IOLs result in high levels of uncorrected distance and near visual acuity and therefore to increased levels of spectacle independence compared with monofocal IOLs.

Despite their benefits of uncorrected visual acuity at multiple distances, multifocal IOLs are associated with certain drawbacks. First, halos and glare are more often reported by patients with a multifocal IOL than with a monofocal IOL.[99,100] Refractive multifocal IOLs appear to be associated with more photic phenomena than diffractive multifocal IOLs.[37] Photic phenomena are among the most frequent reasons for dissatisfaction after multifocal IOL implantation.[101,102] Second, multifocal IOLs are associated with lower contrast sensitivity than monofocal IOLs.[37] Especially in mesopic circumstances[74,103] and in patients with decreased contrast sensitivity due to ocular pathology such as macular degeneration or corneal dystrophies, this loss of contrast sensitivity can become clinically relevant.[41,104,105] The reason for the lower contrast sensitivity could be that multifocal IOLs result in coexisting images, 1 sharp and 1 out of focus, with the light from the latter reducing the detectability of the former image. Diffractive multifocal IOLs appear to be equal or superior to refractive multifocal IOLs with respect to contrast sensitivity.[41,104,105] Although contrast sensitivity in individuals with multifocal IOLs is diminished compared with individuals with monofocal IOLs, it is generally within the normal range of contrast in age-matched phakic individuals.[103,106] Multifocal IOLs, unlike accommodating IOLs, depend on 2 or more fixed focal points that each represent 2 fixed working distances (far and near) at which they deliver a sharp image to the retina (surrounded by a blurred retinal image or images resulting from the other focal point or points). Working distances between these "sweet spots" are associated with suboptimal visual acuity, potentially resulting in difficulties with computer work and similar activities.[38] Traditionally, refractive multifocal IOLs performed better at intermediate than near distance.[24,107] For that reason, refractive multifocal IOLs were implanted bilaterally in patients with strong intermediate vision demands, were combined with a diffractive multifocal IOLs in the nondominant eye, or were combined with mini-monovision strategies leaving the nondominant eye slightly myopic to increase visual function at near distances.[39,107,108] Similarly, diffractive multifocal IOLs have been combined with mini-monovision strategies to increase visual function at intermediate distances.[63] More recently, trifocal diffractive IOLs have been proposed to increase intermediate visual acuity.[109] The introduction of diffractive multifocal IOLs with lower near additions has increased visual acuity at intermediate distance without also decreasing near and distance visual acuity.[33,69,75]

Comparing the performance of different types of multifocal IOLs is hampered for several reasons. First, despite work to develop instruments to measure subjective quality of vision,[110] there is no consensus on which test or questionnaire to use for the measurement of the occurrence and severity of photic symptoms, resulting in the use of many different questionnaires and grading systems. Since photic phenomena such as glare and halos seem to wane with time,[98] a standardized follow-up time would also be essential to compare results of different IOLs in different studies. Second, there is no standardized test for near visual acuity. Some studies use single character reading charts such as Snellen[37] and Early Treatment of Diabetic Retinopathy Study[69] near visual acuity charts. Other studies use function-based tests such as the Minnesota Low Vision Reading Test chart,[111] the Radner chart,[42] and variations thereof[50] measuring reading speed, number of mistakes, and critical character size when using sentences rather than single characters. Third, there is no consensus whether visual acuity should be measured binocularly or monocularly. Binocular visual acuity is generally higher, which might be the result of slight refractive differences between the eyes (resulting in an effect comparable to pseudophakic monovision) or might be the result of more complex and less understood neurological processes. In clinical practice, binocular implantation has been shown to be preferable to monocular implantation.[112] Fourth, contrast sensitivity measurements are currently not standardized, with the CSV-1000,[71,76] the Functional Acuity Test Chart,[36,73,113] the Ginsburg box,[41,69] and the CAT-2000[74,79] systems being most widely used. Discussion exists of what levels should be considered normal given the large standard deviation of contrast sensitivity in normal subjects and whether multifocal IOLs should be compared with age-matched phakic subjects or age-matched subjects with a monofocal IOL. Finally, multifocal IOLs have been associated with higher levels of HOAs than monofocal IOLs.[114] The role of these aberrations, however, is not clear. Not only has the value of HOAs for depth of focus been disputed,[88,89] but the ability of wavefront analyzers to correctly measure aberrations in subjects with a multifocal IOL has not been clarified.[115,116] Lower levels of HOAs in so-called aspheric optics have been shown to be beneficial in monofocal IOLs,[22] but this is less evident in multifocal IOLs.[24,117] Given the lack of consensus on any of these 5 items, a direct comparison of types of multifocal IOLs can be difficult. In a metaanalysis by Cochener et al.,[118] a comparison of visual acuity, spectacle independence, and occurrence of halos with different multifocal IOL designs was performed using random effects Poisson regression models. Compared with refractive multifocal IOLs, diffractive multifocal IOLs were associated with a similar uncorrected distance visual acuity and superior near visual acuity resulting in higher spectacle independence. No significant differences were found in the incidence of halos with different types of multifocal IOLs.

In general, multifocal IOLs are able to provide patients with excellent uncorrected distance and near visual acuity resulting in high levels of spectacle independence. Although superior from a theoretical point of view, currently available accommodating IOLs are unable to offer the same level of near visual acuity.[119] Dissatisfaction following implantation of multifocal IOLs is rare and is often amenable to treatment.[101,102] Some cases of dissatisfaction are due to the occurrence of phenomena inherent to the design of multifocal IOLs (such as glare and halos) and are therefore more difficult to treat.[101,102] This demonstrates the importance of preoperative patient education, careful selection of cases, and individualized weighing of benefits and side-effects of multifocal IOLs.[94,120,121] If these principles are respected, multifocal IOLs can lead to excellent results and can be of great value to present-day ophthalmology.

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